

CP asymmetries at D0

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Using two independent measurements of the semileptonic CP asymmetry in the B_s system, we constrain the CP-violating phase of the B_s system to be $\phi_s = -0.70^{+0.47}_{-0.39}$. The data sample corresponds to an integrated luminosity of 1.1 fb^{-1} accumulated with D0 detector at the Fermilab Tevatron Collider. We also measure the direct CP violating asymmetry in the decay $B^+ \rightarrow J/\psi K^+$ to be $A_{CP}(B^+ \rightarrow J/\psi K^+) = +0.0067 \pm 0.0074(\text{stat}) \pm 0.0026(\text{syst})$. The data corresponds to an integrated luminosity of 1.6 fb^{-1} .

I. SEMILEPTONIC CP ASYMMETRY IN THE B_s SYSTEM

In the Standard Model (SM), the light (L) and heavy (H) mass eigenstates of the mixed B_s^0 system are expected to have sizable mass and decay width differences: $\Delta M_s \equiv M_H - M_L$ and $\Delta \Gamma_s \equiv \Gamma_L - \Gamma_H$. The two mass eigenstates are expected to be almost pure CP eigenstates. The CP-violating mixing phase is predicted [1] to be $\phi_s = (4.2 \pm 1.4) \times 10^{-3}$. New phenomena may alter ϕ_s leading to a reduction of the observed $\Delta \Gamma_s$ compared to the SM prediction $\Delta \Gamma_s^{SM}$: $\Delta \Gamma_s = \Delta \Gamma_s^{SM} \times |\cos \phi_s|$. While $B_s^0 - \bar{B}_s^0$ oscillations have been detected [2] and the mass difference has recently been measured [3], the CP-violating phase remains unknown.

Both CP-violating phase ϕ_s and decay width difference $\Delta \Gamma_s$ of the B_s system were for the first time directly constrained at D0 from the fit to the time-dependent angular distribution of the decay products in the decay sequence $B_s^0 \rightarrow J/\psi \phi$, $J/\psi \rightarrow \mu\mu$, $\phi \rightarrow K^+ K^-$ [6]. The result remained 4-fold ambiguous due to undefined CP-conserving strong phases. The semileptonic asymmetry in the B_s -system, which is in general defined as

$$A_{SL}^s = \frac{N(\bar{B}_s^0 \rightarrow l^+ X) - N(B_s^0 \rightarrow l^- X)}{N(\bar{B}_s^0 \rightarrow l^+ X) + N(B_s^0 \rightarrow l^- X)}, \quad (1)$$

is related to both ϕ_s and $\Delta \Gamma_s$ via

$$A_{SL}^s = \frac{\Delta \Gamma_s}{\Delta M_s} \tan \phi_s. \quad (2)$$

Its measurement gives independent access to ϕ_s , both resolving the mentioned ambiguity and adding statistics to the measurement.

Recently we at D0 accessed the semileptonic asymmetry A_{SL}^s indirectly, by measuring the dimuon asymmetry in the inclusive dimuon sample [4], and directly, by measuring the untagged asymmetry in the exclusive sample of events consistent with the decay $B_s^0 \rightarrow \mu\nu_\mu D_s$, $D_s \rightarrow \phi\pi$ [5]. The combination of the two results gives the best estimate of the charge asymmetry in semileptonic B_s^0 decays: $A_{SL}^s = 0.0001 \pm 0.0090$ [7]. Using (2) and the result $\Delta M_s = 17.8 \pm 0.1 \text{ ps}^{-1}$ from CDF experiment [3] we obtained $\Delta \Gamma_s \cdot \tan \phi_s = A_{SL}^s \cdot \Delta M_s = 0.02 \pm 0.16 \text{ ps}^{-1}$. Using this constraint we repeated the fit to the $B_s^0 \rightarrow J/\psi \phi$ data. In Fig. 1 we show the likelihood contours in $\Delta \Gamma_s$ vs ϕ_s plane without (dashed line) and with (solid line) the constraint from the measurements of the semileptonic asymmetry A_{SL}^s in the B_s^0 decays. The contours indicate error ellipses, $\Delta \ln(\mathcal{L}) = 0.5$, corresponding to the confidence level of 39%.

Finally, from the fit likelihood profile we found for $\phi_s < 0$ the decay width difference and the CP-violating phase in the B_s -system to be $\Delta \Gamma_s = 0.13 \pm 0.09 \text{ ps}^{-1}$, $\phi_s = -0.70^{+0.47}_{-0.39}$. The measurement uncertainty is dominated by limited statistics. The systematic uncertainties include a variation of the background model in the analysis of the decay $B_s^0 \rightarrow J/\psi \phi$, detector acceptance, and sensitivity to the details of track and vertex reconstruction. The results are consistent with the SM predictions [1].

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II. DIRECT CP VIOLATION IN THE DECAY $B^+ \rightarrow J/\psi K^+$

A direct CP asymmetry in the decay $B^+ \rightarrow J/\psi K^+$, $A_{CP}(B^+ \rightarrow J/\psi K^+)$, has recently been measured at D0:

$$A_{CP}(B^+ \rightarrow J/\psi K^+) = \frac{N(B^- \rightarrow J/\psi K^-) - N(B^+ \rightarrow J/\psi K^+)}{N(B^- \rightarrow J/\psi K^-) + N(B^+ \rightarrow J/\psi K^+)} \quad (3)$$

This decay proceeds via $b \rightarrow c\bar{c}s$ transition which is predominantly tree level. The SM gives the order of magnitude estimate $A_{CP}(B^+ \rightarrow J/\psi K^+) = \mathcal{O}(0.003)$ [8], which in the realistic New Physics (NP) models can be enhanced to 0.01 or higher [8].

The events consistent with the decay chain $B^+ \rightarrow J/\psi K^+$, $J/\psi \rightarrow \mu^+\mu^-$ and its charge conjugate were selected. The $J/\psi K$ mass peak was modeled using unbinned likelihood fit to the sum of contributions from $B \rightarrow J/\psi K$, $B \rightarrow J/\psi \pi$, and $B \rightarrow J/\psi K^*$ decays, as well as combinatorial background, see Fig. 2.

The systematic shift from the detector-induced asymmetries was accounted for in the detector model (for the first time applied in [4]), which expresses the number of signal events with the kaon charge q , the sign of the kaon pseudorapidity γ , and the solenoid polarity at which the event was recorded β in terms of the kaon charge asymmetry A and various detector asymmetries A_i (see section IV of [4] for the explanation of N , ϵ^β , and different A_i):

$$n_q^{\beta\gamma} = \frac{1}{4} N \epsilon^\beta (1 + qA) (1 + q\gamma A_{fb}) (1 + \gamma A_{det}) (1 + q\beta\gamma A_{q\beta\gamma}) (1 + q\beta A_{q\beta}) (1 + \beta\gamma A_{\beta\gamma}). \quad (4)$$

The initial data sample of Fig. 2 was divided into subsamples corresponding to eight possible combinations of β , γ , and q , in each subsample the unbinned fit was performed to find the number of events in the $J/\psi K$ peak, $n_q^{\beta\gamma}$, and the system (4) was solved for all asymmetries.

A systematic shift from charge asymmetric kaon interactions with detector material was estimated from data by comparing the exclusive decay $c \rightarrow D^{*+} \rightarrow D^0 \pi^+$, $D^0 \rightarrow \mu^+ \nu_\mu K^-$ and its charge conjugate. To account for the momentum dependence of the kaon cross-section [9], the kaon asymmetry in the D^* sample was measured in kaon momentum bins to convolve it with the PDF of the kaon momentum in the $J/\psi K$ sample.

Finally, after subtracting kaon asymmetry, we obtained $A_{CP}(B^+ \rightarrow J/\psi K^+) = +0.0067 \pm 0.0074(\text{stat}) \pm 0.0026(\text{syst})$, which is consistent with the PDG-2007 world average, $A_{CP}(B^+ \rightarrow J/\psi K^+) = +0.015 \pm 0.017$ [9], but has a factor of two better precision, thus providing the most stringent bounds for new models predicting large values of $A_{CP}(B^+ \rightarrow J/\psi K^+)$. The measurement uncertainty is mainly due to limited statistics. Systematic uncertainty is largely dominated by the variation of the $J/\psi K$ mass peak model.

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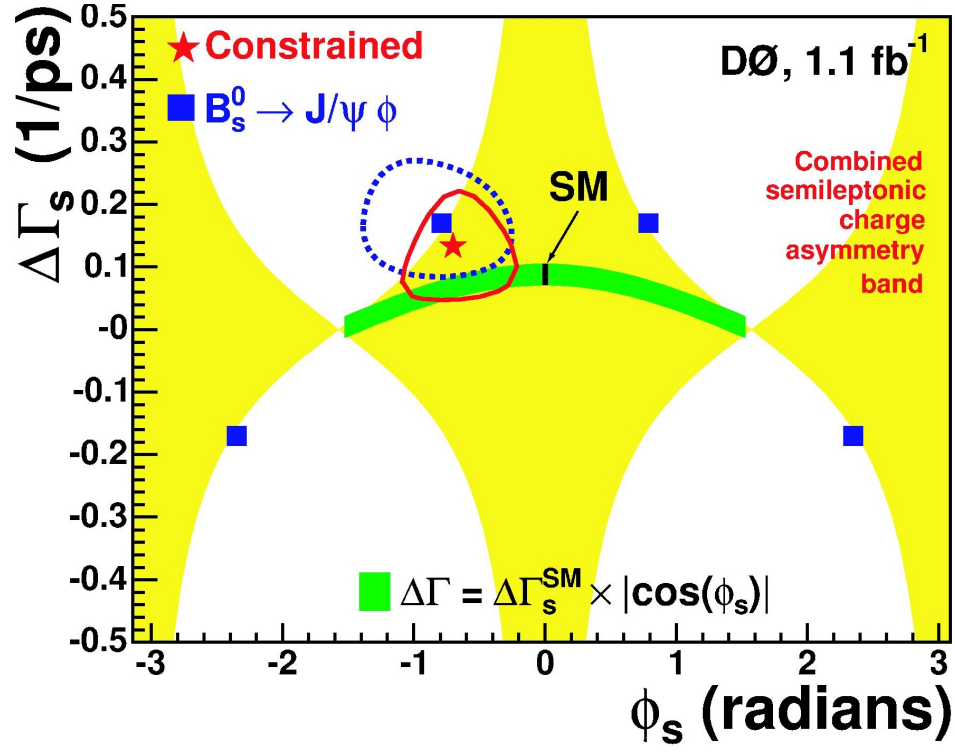


FIG. 1: The error ellipse ($\Delta \ln(\mathcal{L}) = 0.5$) in the plane $(\Delta \Gamma_s, \phi_s)$ for the fit to the $B_s^0 \rightarrow J/\psi \phi$ data (dashed line) and for the fit with the constraint from the two D0 measurements of the charge asymmetry A_{SL}^s in semileptonic B_s^0 decays (solid line). The central values of four solutions of the unconstrained fit are indicated by squares. Also shown is the band representing the relation $\Delta \Gamma_s = \Delta \Gamma_s^{SM} \times |\cos \phi_s|$ with $\Delta \Gamma_s^{SM} = 0.088 \pm 0.017 \text{ ps}^{-1}$ [1] (dark shade) and the area corresponding to $\Delta \Gamma_s \cdot \tan \phi_s = 0.02 \pm 0.16 \text{ ps}^{-1}$ [3] (light shade).

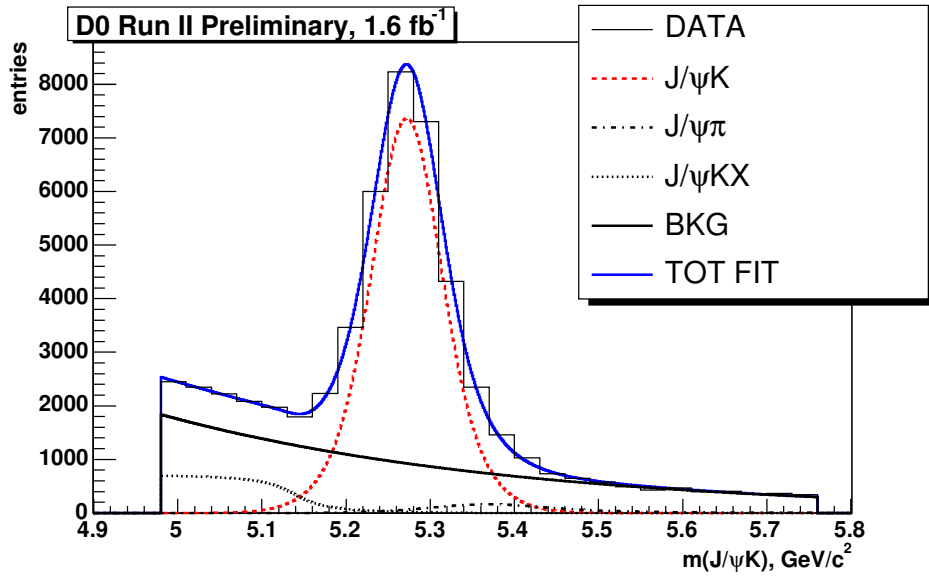


FIG. 2: Result from the unbinned fit of the invariant mass distribution of the $J/\psi K$ system in the $B^+ \rightarrow J/\psi K^+$ decay and its charge conjugate.